A Comparison of Oxygen Supply Systems for Combustion Applications

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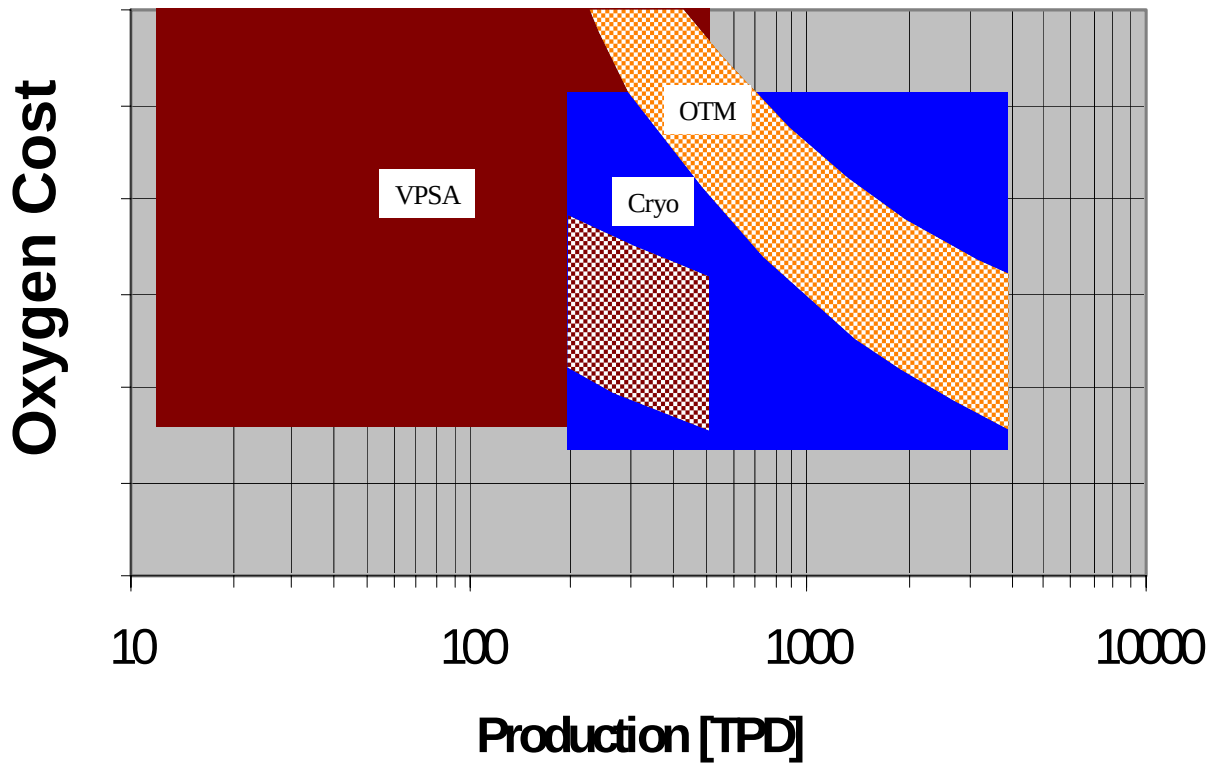
Presentation Outline

- Oxygen Supply Systems
- Economic Comparisons
- Summary

Oxygen Supply Systems

- Air
- Cryogenic Separation
  - Most mature technology
  - Substantial savings on scale up
- VPSA
  - Lowest cost source of oxygen @ < 200 tpd
- Ceramic Membranes
  - High purity oxygen
  - Requires significant air compression
- Advanced OTM integrated boiler

Comparison of Oxygen Supply Systems



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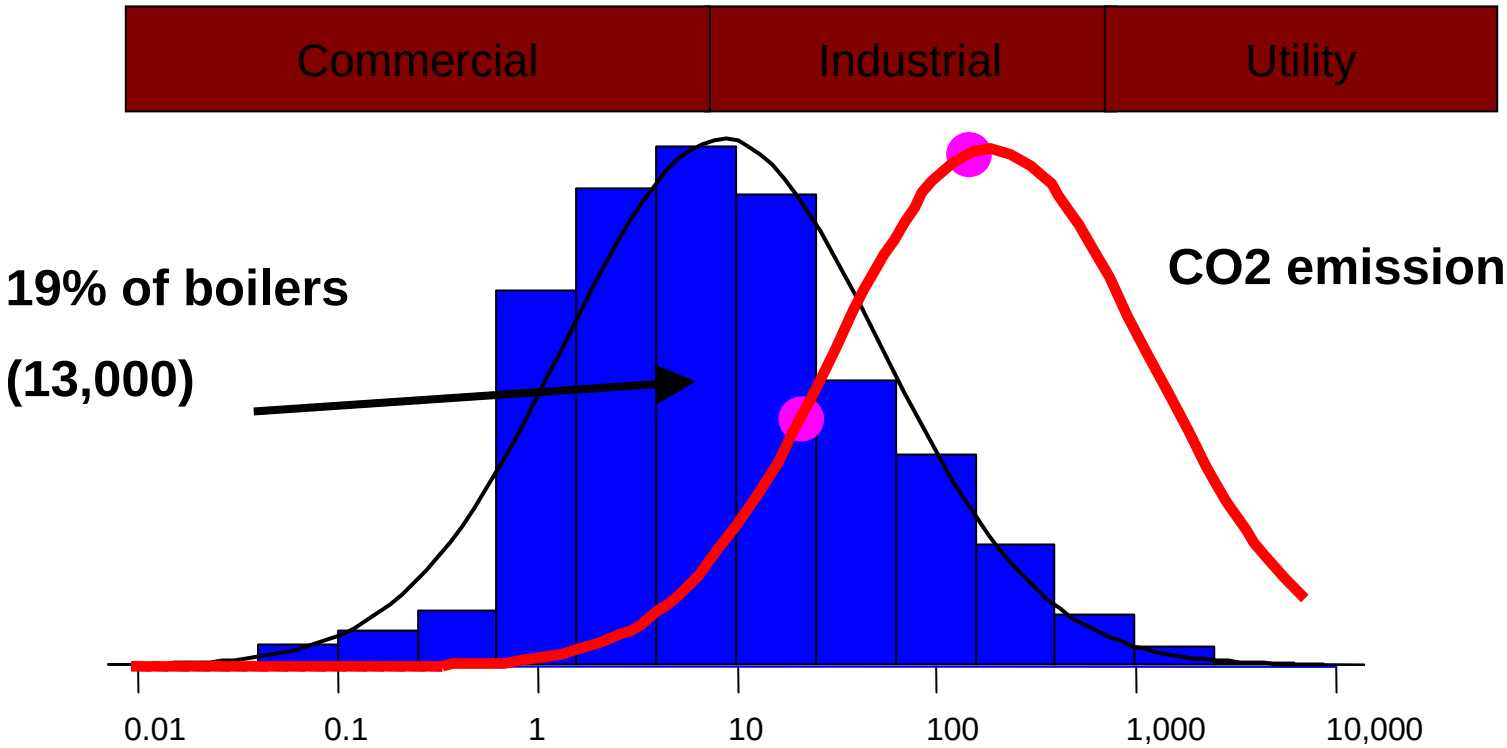
CO_2 Capture and Sequestration



Based on EPA Boiler Inventory database

Economic Comparisons

	Air fired Boiler	VPSA Boiler	Cryo Boiler	Ceramic membrane boiler	Advanced OTM boiler
Capital Cost ($MM)					
Boiler	1.9	1.9	1.9	1.9	2.9
Annualized capital cost	0.32	0.32	0.32	0.32	0.5
Operating Costs ($MM)					
Annual Fuel @$5/MMBTU	5.9	5.3	5.3	5.3	5.3
Annual Power @ $0.07/kWh	0.02	0.01	0.01	0.01	0.3
Annual Cost of Oxygen		2.1	3	6.2	
Total Operating Costs	5.9	7.4	8.3	11.5	5.6
Combined annual Cost ($MM)	6.2	7.7	8.6	11.8	6.1

- 100,000 lb/hr steam
  - ~ 250 tpd/O_2
- Lowest cost of oxygen from VPSA
  - Cost of oxygen prohibitive

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Economic Comparisons

	Air fired Boiler	VPSA Boiler	Cryo Boiler	Ceramic membrane boiler	Advanced OTM boiler
Capital Cost ($MM)					
Boiler	6.0	6.0	6.0	6.0	9.0
Annualized capital cost	1.0	1.0	1.0	1.0	1.54
Operating Costs ($MM)					
Annual Fuel @$5/MMBTU	29.3	26.3	26.3	26.3	26.3
Annual Power @ $0.045/kWh	0.053	0.03	0.028	0.028	1.5
Annual Cost of Oxygen		10.5	9.6	14.1	
Total Operating Costs	29.4	36.8	35.9	40.5	27.8
Combined annual Cost ($MM)	30.4	37.8	36.9	41.5	29.3

- 500,000 lb/hr steam
  - ~1250 tpd/O_2
- Lowest cost oxygen from Cryo
  - Cost prohibitive

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Economics under Carbon Constraint

	Air fired Boiler	VPSA Boiler	Cryo Boiler	Advanced OTM boiler
Capital Cost ($MM)				
Boiler	1.9	1.9	1.9	2.9
CO2 capture system	5.9	1.9	1.9	1.9
Total Capital Cost	7.8	3.8	3.8	4.8
Annualized capital cost	1.3	0.65	0.65	0.82
Operating Costs ($MM)				
Annual Fuel @$5/MMBTU	5.9	5.3	5.3	5.3
Annual Power @ $0.07/kWh	0.02	0.01	0.01	0.3
Annual Cost of Oxygen		1.7	2.4	
Total Operating Costs	5.9	6.9	7.7	5.6
CO2 Capture costs ($MM)				
Annual Steam @ $3.5/MMBTU	1.1			
Annual Power @ $0.07/kWh	0.4	0.78	0.77	0.77
Annual Chemicals	0.29			
Total CO2 Capture Costs	1.8	0.78	0.77	0.77
Combined annual Cost ($MM)	9.0	8.4	9.1	7.2

100,000 lb/hr steam

- **VPSA oxygen results in net CO_2 cost of ~$25/ton**
- **Advanced OTM results in net CO_2 cost ~$5/ton**

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Economics under Carbon Constraint

	Air fired Boiler	VPSA Boiler	Cryo Boiler	Advanced OTM boiler
Capital Cost ($MM)				
Boiler	6.0	6.0	6.0	9.0
CO2 capture system	30.5	6.0	6.0	6.0
Total Capital Cost	36.5	12.0	12.0	15.0
Annualized capital cost	6.2	2	2.1	2.6
Operating Costs ($MM)				
Annual Fuel @$5/MMBTU	29.3	26.3	26.3	26.3
Annual Power @ $0.045/kWh	0.05	0.03	0.03	1.5
Annual Cost of Oxygen		10.5	9.6	
Total Operating Costs	29.4	36.8	35.9	27.8
CO2 Capture costs ($MM)				
Annual Steam @ $5/MMBTU	5.9			
Annual Power @ $0.045/kWh	2.1	0.77	0.77	0.77
Annual Chemicals	1.5			
Total CO2 Capture Costs	9.5	0.77	0.77	0.77
Combined annual Cost ($MM)	45.0	39.6	38.7	31.1

500,000 lb/hr steam

- Cryo oxygen results in net CO_2 cost of <$20/ton
- Advanced OTM results in net CO_2 cost ~$4/ton

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Summary

- Oxygen supply systems add substantial cost to conventional boiler
  - Efficiency savings offset by cost of oxygen
- "Conventional" ceramic membrane technology does not offer advantage over existing oxygen supply systems
- Advanced OTM combustion has potential for significant cost reduction
- CO_2 capture <$20/ton possible with current technology
- Advanced OTM combustion can lower to <$5/ton CO_2

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Any Questions?

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